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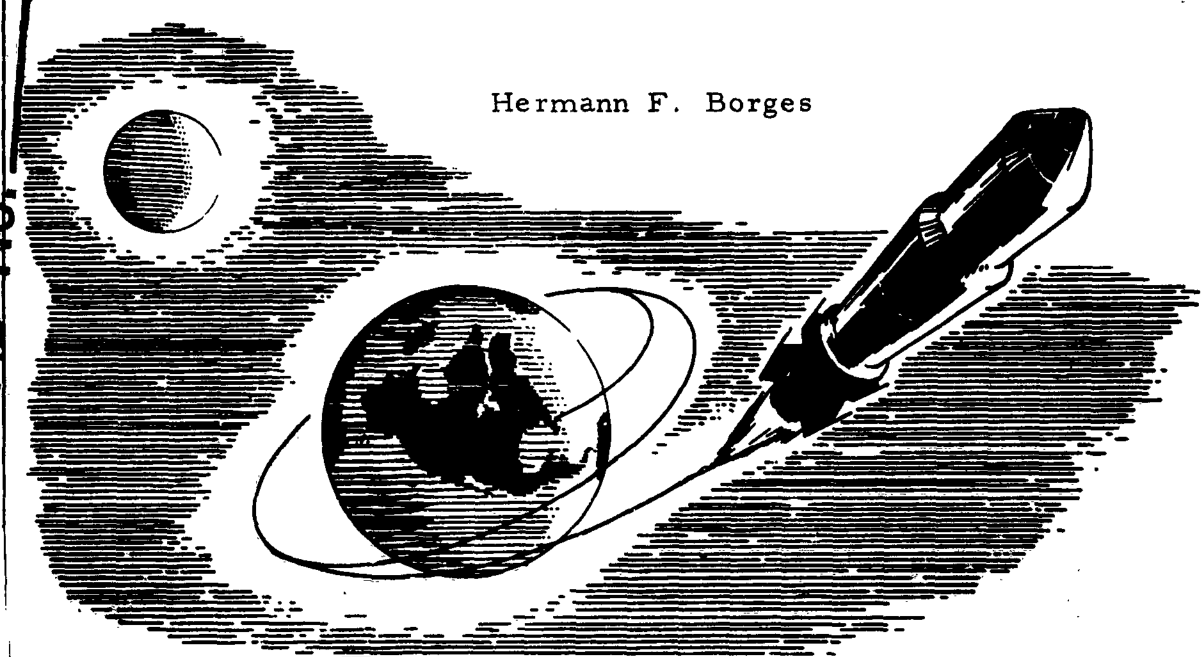
TECHNICAL REPORT

ANALYSIS OF ADVANCED TRACK PERFORMANCE CHARACTERISTICS

Hermann F. Borges



OFFICE OF RESEARCH ANALYSES
HOLLOMAN AIR FORCE BASE
NEW MEXICO

January 1963

ANALYSIS OF ADVANCED TRACK PERFORMANCE CHARACTERISTICS

by

Hermann F. Borges

Science and Engineering Division

Office of Research Analyses

OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
Holloman Air Force Base, New Mexico

January 1963

FOREWORD

This report was prepared for the Test Track Division, Deputy for Guidance Test, Air Force Missile Development Center, Holloman AFB, New Mexico.

The work supports Project 5928, Hypersonic Track Development, and provides information on the limitations of rocket sled performance on hypersonic track facilities.

ABSTRACT

Velocity and acceleration profiles of rocket sleds on an advanced track were determined, based on existing and advanced rocket engine and sled designs. Sled families with a unit thrust of 100,000 pounds, using propellants of different specific impulse, were postulated. Rocket assembly weight and payload weight were expressed in terms of thrust, and tank and structural weight in terms of propellant weight. The upper limit for rocket sleds using liquid oxygen and liquid hydrogen as propellants is about 5400 feet per second in ambient air density at one percent payload-to-thrust ratio. This speed will increase to about 8000 feet per second if the track is enclosed in an evacuated tube at about one-third of the ambient air density. To attain this performance a track about 40 statute miles long is required.

This report is approved for publication.

James H. Ritter

JAMES H. RITTER
Colonel, USAF
Commander, Office of Research Analyses

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ANALYSIS OF ADVANCED TRACK PERFORMANCE CHARACTERISTICS

I. INTRODUCTION

Rocket sleds have proved to be a useful tool for many research and development purposes. However, present existing tracks allow only speeds which are below those presently developed in aircraft and rocket design.

The purpose of this study is to determine maximum attainable speed and acceleration profiles using existing systems or systems that will be operative in the near future.

The performances of sled families with a 100,000-pound thrust engine, considered as a unit, are calculated over a certain burning time range for rocket systems with different specific impulses and different propellant feed systems.

A small-gauge track vehicle similar to a monorail sled is selected for this study. The present dual-rail track systems require slipper beams which create unnecessary drag and weight, reducing the performance considerably. Sled weight configurations are computed using certain constant functions. Rocket assembly weight and payload weight are expressed as a function of thrust. Tank and structural weight are expressed as a function of propellant weight. Propellant weight, for each system, is a function of thrust and burning time. Air drag and propellant weight are the dominant factors influencing sled performance.

Aerodynamic data for this vehicle type were investigated in two Technical Reports: In AFMDC-TR-60-30, September 1960, wind tunnel investigations for basic and advanced rocket sled configurations were conducted from M = 0.5 to M = 4.0; and AFOSR/DRA-62-18, September 1962, investigated wind tunnel performance of a spike-bluff body configuration for a monorail rocket sled from M = 2.0 to M = 5.0.

The performance data calculated in this study will be valid for every amount of thrust as long as the following parameters remain constant (as is explained in the following paragraph)

(1) Specific impulse

(2) Thrust-to-frontal area ratio

(3) Payload in percent of thrust

(4) Air density

(5) Burning time

A sled with 200,000 pounds thrust, a LOX-RP1 engine, a 1 percent payload, and a frontal area of 2 × 8.3 square feet will have the same acceleration characteristics and velocity performance as the 100,000-pound thrust sled calculated in this study with a LOX-RP1 engine, a 1 percent payload, and an 8.3 square foot frontal area for the same burning time.

The performance calculations show that a sled with a maximum specific impulse rocket system, such as LOX-Liquid Hydrogen, an optimum designed sled body with a frontal area of about 8 square feet, and a 1 percent payload-to-thrust ratio, will reach a maximum speed of about 5400 ft/sec after a burning time of 40 seconds. A sled with the present pressurized LOX-Alcohol rocket system in an optimum sled body as mentioned before would reach a maximum speed of 3200 ft/sec after 30 seconds burning time.

Any additional weight required for sled-borne braking systems is not included in this performance study.

Sled accelerations higher than 10g during the acceleration phase can only be attained with burning times of 10 seconds or less. One-stage vehicles will be able to create a 10g environment up to 10 seconds under full thrust condition. With the help of staging this time can be extended. Higher g-loads can be maintained for longer periods in the braking period only. If higher speeds and accelerations are required, a reduction of the air density must be provided.

Assuming the sleds are running in a wide tube in which the air density is reduced to 1/3 of the normal atmosphere, a sled equipped with a LOX-Hydrogen rocket will attain a speed of about 8000 ft/sec after a burning time of 40 seconds. The present pressurized LOC-Alcohol sled would reach about 4200 ft/sec with 30 seconds running time. The acceleration profiles are much higher in this case. An acceleration of 15g can be maintained over 10 seconds and 10g over 20 seconds. The distance traveled by the sled at burnout increases considerably. A LOX-Hydrogen sled with a burning time of 40 seconds has traveled 24.5 statute miles in ambient air density and 32 statute miles in 1/3 ambient air density at burnout. A LOX-Alcohol pressurized system sled with burning time of 30 seconds has traveled about 10 statute miles at burnout.

The necessary total length of a high-performance track including the coasting and braking phase would be restricted by geographic conditions and the given mission requirements, which are not to be investigated in this study.

II. SLED PARAMETERS AND THEIR INFLUENCE ON THE PERFORMANCE

The most important parameters of a sled which influence the performance are:

(1) Rocket system

(2) Propellants, volume and weight

(3) Tanks

(4) Sled structure and configuration

(5) Payload and performance in acceleration phase

(6) Coasting and braking phase

Rocket Systems

Table I presents a comparison of various rocket systems which are presently available or will be available in the near future. Depending on the propellant combination, values are given for the specific impulse and for the weight of the rocket assemblies, including pumps and feeding lines in percent of the thrust. Comparing rocket systems with different specific impulse and with a thrust of 100,000 pounds as a unity, we can derive the weights for all subsystems of the sled as a function of this unity. The weight of the rocket assembly can be expressed as a fixed relationship to the thrust. In this subsystem are included all engine parts, such as nozzle, combustion chamber, pumps, including power system, valves, and feed lines.

The weight of a rocket assembly subsystem for missiles is at the present time about 1.2 percent of the thrust (Table I) and is expected to decrease to 0.75 percent in the near future. Sled-rocket assembly systems are about two to three times heavier than those for missiles in use. It is anticipated that in the next three to five years it will be possible to build much lighter rocket assemblies for repeated use in the track environment. For the purpose of this study it is assumed that the pump-fed liquid rocket assembly subsystems for sleds weigh about 1.4 percent of the thrust. The weight of the pressurized liquid rocket subassembly system is assumed to be 1 percent of the thrust, since no weight for pumps and power supply has to be included.

The nozzle, plus casing weight of a present solid-propellant sled rocket, is about 5 percent of the thrust for a burning time of 10 seconds. Since there are efforts under way to decrease this heavy weight in the missile field, it is assumed for the purpose of this study that it will be possible to decrease this ratio to about 2 percent, to about 3 percent for a burning time of 20 seconds, and to about 4 percent for a burning time of 30 seconds.

Tables II and III tabulate the rocket assembly weight for 100,000-pound thrust pump-fed liquid rockets. Table IV tabulates rocket assembly weight for a pressurized system, and Table V presents a solid system.

Propellant Weight

As soon as burning times longer than 10 seconds are considered, the total propellant weight is dominant over all other weights and dictates the performance of the sled.

The propellant weight is a function of thrust, specific impulse, and, consequently, the flow rate of each propellant configuration. The function is linear-increasing with burning time. The best specific impulse will therefore result in the lowest propellant weight for equal burning time and equal thrust.

For liquid propellant pressurized rocket systems the weight of the pressurized gas has to be added to the fuel and oxidizer weight.

Tanks

The tank weight depends on four main factors:

(1) Volume of propellants V (in^3)

(2) Operational internal tank pressure P (psi)

(3) Tank material strength/density ratio $\frac{F_t}{d}\left(\frac{psi}{lbs/in^3}\right)$

(4) The factor of safety j

The weight of a cylindrical tank is given by the following equation:

$$W = 2 \cdot j \cdot \frac{d}{F_t} \cdot p \cdot V \cdot \frac{K + 1/2}{K + 2/3}$$

The factor $K = \frac{l}{D}$ and represents the ratio of tank length to tank diameter. The most important factor besides burst pressure and volume is the strength/density ratio of the tank material; e.g., for:

Stainless Steel $\frac{d}{F_t} = \frac{0.295}{220000} = \frac{1}{745000}$

Aluminum Alloy $= \frac{0.100}{60000} = \frac{1}{600000}$

Titanium Alloy $= \frac{0.171}{232000} = \frac{1}{1360000}$

The design ultimate stress ($F_t{}'$) is not the material ultimate stress.

However, what must be considered is the allowable ultimate working stress, including considerations of fatigue and notch sensitivity of the material. Materials which have low yield stress relative to their ultimate stress will be critical at proof pressure.

The tank weights used in this study are calculated along this line, including 30 percent additional weight for baffles and fixtures. Supporting structures are not included. It is assumed that every tank is supported in such a manner that additional stresses superimposed from the sled body during the run are of secondary influence.

The propellant inlaid pressure for pump feed systems is assumed to vary between 25 to 35 psi. Additional tank pressure is created in the acceleration phase depending on the g-load values. Therefore, the tanks have to withstand maximum operational pressures up to 80 to 85 psi.

The propellant tanks of the pressurized systems are calculated for an operational pressure of about 800 psi. To maintain this pressure during the entire run, the tanks for the pressurizing gas have to be designed for a safe pressure of 2400 psi. These high pressures, which are needed for the continuous uniform operation of a pressurized system, contribute to high tank weights leading to a considerable performance loss (Figure 3).

The casings of solid propellant rockets are subject to high internal pressure during the burning phase. Solid propellant rockets are therefore somewhat lower in performance than the liquid rockets due to their considerable weight, which ranges between that of pump feed and pressurized systems.

Configuration and Weight of the Sled Structure

The size and weight of the sled structure depend mainly on the volume of the propellants, the size of the necessary tanks, and finally on the operating pressure for which the tanks have to be designed.

For high-speed sleds considered in this study, the configuration of the sled structure plus tanks is essential. Small frontal areas with low C_D-factors are required to reduce the drag as much as possible. Sleds with longer burning time require, therefore, slender bodies which have additional skin friction of considerable influence on the amount of the drag. To avoid high bending moments on the slender tanks more supports are needed.

Using a narrow gauge track, slipper beams can be avoided since this would create a considerable increase of the drag coefficient. According to these considerations a spike body sled configuration similar to a monorail sled was chosen in this study.

The data used in this study are taken from wind tunnel investigations conducted under Contract AF29(600)-2839, Project 7856, Task 78544. The spike-bluff body combination of a monorail rocket sled was investigated in the range from $M = 2.0$ to $M = 5.0$. Selected for this study were the data of a model configuration with a nose shoulder radius zero, spike location in the center of the circular frontal area, and a spike diameter of .10 the diameter of the sled body. Figure 1 shows the shape of the drag curve including ground interference plotted over the Mach number for a sled body as mentioned above. The drag coefficient curve of a missile including fins is shown in comparison to this curve.

The weights of the sleds are derived from the present design state for sleds with 10 seconds burning time. For sleds with longer burning time the structural weights are progressively increased according to the increase of propellant weight and tank dimensions (Tables II to V).

Payload and Performance

Since the thrust has been used as a unity the payload is expressed in percent of the thrust. For the selected 100,000-pound thrust unity, three payload steps are considered:

(1) One-half percent equal to 500-pound payload

(2) One percent equal to 1,000-pound payload

(3) Two percent equal to 2,000-pound payload

The performance of rocket sleds with this payload range and with a burning time range between 10 and 40 seconds has been calculated for:

(1) LOX-Hydrogen rocket sleds with pump feed system

(2) LOX-RP1 rocket sleds with pump feed system

(3) LOX-Alcohol rocket sleds with pressurized system

(4) Solid propellant sleds

In Tables II to V the weight and performance data for these sleds are given, all based on the same frontal area of 8.3 square feet, and on the same aerodynamic quality. The calculated weight data are plotted over burning time in Figure 2 and the maximum attainable speeds over burning time in Figure 3.

The flat slopes between 30 and 40 seconds burning time of the systems 1, 2, and 4 show that a further increase of burning time will not gain much in speed. The last of the three liquid systems will reach its maximum speed with a burning time of about 25 seconds.

The acceleration profiles of the different systems (Figure 4) show that g-loads higher than 10 can only be achieved with burning times of 10 seconds and less. These g-loads vary considerably during the burning time if the sled is running with full thrust. Longer burning times create more or less constant g-loads but of lower level (Figures 4 and 5).

If it is possible to run the sleds in a lower atmospheric density, higher speeds and better acceleration levels can be reached. Figure 6 shows the attainable speed at an air density reduced to one-third of the normal atmosphere at Holloman. In contrast to Figure 3, sleds with burning time over 40 seconds will promise a further increase in speed. A change of payload range is of much higher influence than in normal density. Maximum velocities over 8,000 ft/sec can be attained with the LOX-Hydrogen sled, and the LOX-Alcohol pressurized sled will reach 4,200 ft/sec after 30 seconds burning time, reaching its maximum at over 40 seconds.

The acceleration profiles show a much smoother tendency. An acceleration of 15 g can be reached for 10 seconds duration, and over 10 g for 20 seconds burning time. The LOX-Hydrogen sled profiles are nearly constant for 20 to 30 seconds burning time (Figure 7).

For sleds with lower specific impulse, a possibility of thrust throttling exists to hold g-loads constant over a longer time. Unfortunately, a serious restriction exists for the use of such high-speed sleds besides cost and technical difficulties. The necessary travel distance to obtain the previously discussed performances will restrict their use in the higher ranges.

Figure 8 presents the traveled distance of the discussed sled systems plotted over burning time in normal and in one-third air density.

Coasting and Braking Phase

Since the structural weight of the sleds includes no weight for an extra brake besides the spike, external braking systems must be applied. Due to the high drag forces and the heat created by air friction, the nose section of the sled must be designed to withstand this special environment and provides, in the higher speed zone with "spike in," an excellent air brake.

But in the lower speed range, a piston type brake has to be applied to decelerate the sled in a short distance. A trumpet-like tube, slotted at the wide entrance and providing increasing compression over the length, will provide a braking system which can be used without any additional structural weight on the sled body.

III. REQUIRED TRACK LENGTHS

The total required track lengths are calculated for the entire run of a few different sleds as follows:

(1) LOX-Hydrogen Sled

Sled Parameters:

Burning time	30 seconds
Sled weight at burnout	6250 pounds
Maximum speed	5270 ft/sec
Payload weight	1 percent of thrust

After a 9-second coasting phase and a "spike in" phase of 21 seconds, sled speed is 659 ft/sec. Using a 10 g braking force, the necessary length of the tube will be 0.2 statute miles.

Track Length:

Acceleration phase	17.6 statute miles
Coasting and "spike in" phase	11.7
Braking tube	0.2
Total track length	29.5 statute miles

(2) LOX-RP1 Sled

Sled Parameters:

Burning time	30 seconds
Sled weight at burnout	7100 pounds
Maximum speed	4180 ft/sec
Payload weight	1 percent of thrust

After a 9-second coasting phase and a "spike in" phase of 12 seconds, sled speed is 1020 ft/sec. Using a 10 g braking force, the necessary length of the tube will be 0.3 statute miles.

Track Length:

Acceleration phase	14.4 statute miles
Coasting and "spike in" phase	10.3
Braking tube	0.3
Total track length	25.0 statute miles

If it is required to brake the sled with a constant 10 g force from the maximum speed down to zero, the spike must be "in" after 3 seconds and a braking tube of about 4.7 statute miles is required.

Track Length:

Acceleration phase	14.4 statute miles
Coasting and "spike in" phase	2.5
Braking tube	4.7
Total track length	21.6 statute miles

(3) LOX-Alcohol Sled

Sled Parameters:

Burning time	30 seconds
Sled weight at burnout	14,000 pounds
Maximum speed	3270 ft/sec
Payload weight	1 percent of thrust

After 24 seconds with "spike in," the sled decelerates to 1034 ft/sec. Using a 5-g braking force, the necessary length of the tube will be 0.6 statute miles.

Track Length:

Acceleration phase	9.8 statute miles
"Spike in" phase	8.1
Braking tube	0.6
Total track length	18.5 statute miles

(4) LOX-Hydrogen Sled - 1/3 Atmospheric Density

Sled Parameters:

Burning time	30 seconds
Sled weight at burnout	6250 pounds
Maximum speed	7690 ft/sec
Payload weight	1 percent of thrust

After a 9-second coasting phase in 1/3 density, a 12-second coasting phase in normal density, and a 12-second "spike in" phase, sled speed is 905 ft/sec. Using a 10g braking force, the necessary length of the tube will be 0.1 statute miles.

Track Length:

Acceleration phase (1/3 density)	22.3 statute miles
Coasting (1/3 density)	9.1
Coasting (normal density)	5.9
"Spike in" phase (normal density)	2.3
Braking tube	0.1
Total track length	39.7 statute miles

IV. PROBLEM AREAS

As mentioned in the introduction considerable development work has to be done in various areas to obtain the above-calculated maximum performances. Further development is needed in the following subsystem areas:

(1) Pump-fed sled rocket engine systems

(2) Lightweight aerodynamically clean tank-sled-bodies withstanding aerodynamic drag forces and heat

(3) Slipper development for hypersonic speeds

(4) External tube-type brake systems

(5) Space-time systems measuring hypersonic speeds with the necessary accuracy

(6) A narrow gauge track bed avoiding shock wave reflection as much as possible.

TABLE I

Comparison of Rocket Engines Used in the Sled Performance Study

Type	Propellant	Average Specific Impulse seconds	Thrust 1000 pounds	Flow Rate lb/sec	Flow Rate per 1000-Pound Thrust lb/sec	Weight of Rocket Assembly in Percent of Thrust pounds	Burning Time seconds
(A) New Operative Liquid Propellant Rocket Engines							
F-1	LOX-RP1	265	1500	5650	3.77	1.2	140
Hypergolic	N_2O_4- $\frac{\text{UDMH}}{\text{hydrazine}}$	263	214	814	3.8	1.2	160
(B) Liquid Propellant Rocket Engine in Development							
J-2	LOX-Hydrogen	362	200	470	2.35	1.2	140
(C) Present Sled Rocket Engine Pressurized System							
AJ-10-33	LOX-Alcohol	235	114		4.2	1.0	10
(D) Representative Solid Propellant Rocket						Casing + Nozzle	
	Solid	197	340	1612	4.75	3	20
(E) Present Solid Propellant Sled Rocket							
Megaboom	Solid	190	100	553	5.5	5	10

TABLE II

LOX-Hydrogen Sled Family - 100,000-Pound Thrust

Frontal Area 8.3 square feet, Spike Body

Payload in Percent of Thrust:	1/2	1	2	1/2	1	2	1/2	1	2	1/2	1	2
Sled Equipped with Tanks for:	(A) 10 sec Burning Time			(B) 20 sec Burning Time			(C) 30 sec Burning Time			(D) 40 sec Burning Time		
Rocket Assembly (lb)	1400			1400			1400			1400		
Propellant (lb)	2600			5200			7800			10400		
Tanks (lb)	150			200			330			500		
Structure (lb)	1850			2200			2770			3300		
Total Sled Weight (lb)	6000	6000	6000	9000	9000	9000	12300	12300	12300	15600	15600	15600
Payload (lb)	500	1000	2000	500	1000	2000	500	1000	2000	500	1000	2000
Start Weight (lb)	6500	7000	8000	9500	10000	11000	12800	13300	14300	16100	16600	17600
Expendable Propellant (lb)	2350	2350	2350	4700	4700	4700	7050	7050	7050	9400	9400	9400
Burnout Weight (lb)	4150	4650	5650	4800	5300	6300	5750	6250	7250	6700	7200	8200
Start (g)	15.4	14.3	12.5	10.52	10.0	9.1	7.8	7.5	7.0	6.2	6.03	5.7
Velocity at Burnout (ft/sec)	4110	3960	3600	5140	5010	4700	5360	5270	5115	5500	5410	5250
Burnout (g)	9.6	9.4	8.7	3.9	4.3	5.0	2.4	2.34	3.04	1.3	1.43	1.52
Traveled Distance at Burnout (statute miles)		4.05			11.1			17.5			24.5	

TABLE III

LOX-RP1 Sled Family - 100,000-Pound Thrust

Frontal Area 8.3 square feet, Spike Body

Payload in Percent of Thrust:	1/2	1	2	1/2	1	2	1/2	1	2	1/2	1	2
Sled Equipped with Tanks for:	(A) 10 sec Burning Time			(B) 20 sec Burning Time			(C) 30 sec Burning Time			(D) 40 sec Burning Time		
Rocket Assembly (lb)	1400			1400			1400			1400		
Propellant (lb)	4200			8400			12600			16800		
Tanks (lb)	170			340			500			500		
Structure (lb)	2030			2360			3000			3900		
Total Sled Weight (lb)	7800	7800	7800	12500	12500	12500	17500	17500	17500	22600	22600	22600
Payload (lb)	500	1000	2000	500	1000	2000	500	1000	2000	500	1000	2000
Start Weight (lb)	8300	8800	9800	13000	13500	14500	18000	18500	19500	23100	23600	24600
Expendable Propellant (lb)	3800	3800	3800	7600	7600	7600	11400	11400	11400	15200	15200	15200
Burnout Weight (lb)	4500	5000	6000	5400	5900	6900	6600	7100	8100	7900	8400	9400
Start (g)	12.05	11.35	10.2	7.7	7.4	6.9	5.55	5.4	5.12	4.34	4.24	4.07
Velocity at Burnout (ft/sec)	3790	3610	3300	4670	4520	4290	4950	4810	4660	5080	5010	4840
Burnout (g)	10.4	9.80	9.2	5.75	5.75	5.5	3.67	3.92	3.9	2.5	2.62	2.75
Traveled Distance at Burnout (statute miles)		3.55			9.05			14.5			20.3	

TABLE IV

LOX-Alcohol Sled Family - 100,000-Pound Thrust

Frontal Area 8.3 square feet, Pressurized System, Spike Body

Payload in Percent of Thrust:	1/2	1	2	1/2	1	2	1/2	1	2
Sled Equipped with Tanks for:	(A) 10 sec Burning Time			(B) 20 sec Burning Time			(C) 30 sec Burning Time		
Rocket Assembly (lb)	1000			1000			1000		
Propellant (lb)	4850			9700			14500		
Tanks (lb)	1300			2600			3900		
Nitr. + Tanks (lb)	2200			4300			6400		
Structure (lb)	1650			2600			3400		
Total Sled Weight (lb)	11000	11000	11000	20200	20200	20200	29200	29200	29200
Payload (lb)	500	1000	2000	500	1000	2000	500	1000	2000
Start Weight (lb)	11500	12000	13000	20700	21200	22200	29700	30200	31200
Expendable Propellant (lb)	4200	4200	4200	8400	8400	8400	12600	12600	12600
Burnout Weight (lb)	7300	7800	8800	12300	12800	13800	17100	17600	18600
Start (g)	8.7	8.32	7.7	4.82	4.72	4.5	3.37	3.32	3.2
Velocity at Burnout (ft/sec)	2900	2770	2510	3330	3240	3090	3370	3270	3180
Burnout (g)	8.6	8.25	7.35	4.65	4.50	4.25	3.25	3.15	3.0
Traveled Distance at Burnout (statute miles)		2.77			6.26			9.9	

TABLE V

Solid Propellant Sled Family - 100,000-Pound Thrust

Frontal Area 8.3 square feet, Spike Body

Payload in Percent of Thrust:	1/2	1	2	1/2	1	2	1/2	1	2
Sled Equipped with Casing for:	(A) 10 sec Burning Time			(B) 20 sec Burning Time			(C) 30 sec Burning Time		
Casing + Nozzle (lb)	1950			3280			4150		
Propellant (lb)	5250			10500			15750		
Structure (lb)	2100			2520			3200		
Total Sled Weight (lb)	9300	9300	9300	16300	16300	16300	23100	23100	23100
Payload (lb)	500	1000	2000	500	1000	2000	500	1000	2000
Start Weight (lb)	9800	10300	11300	16800	17300	18300	23600	24100	25100
Expendable Propellant (lb)	4750	4750	4750	9500	9500	9500	14250	14250	14250
Burnout Weight (lb)	5050	5550	6550	7300	7800	8800	9350	9850	10850
Start (g)	10.2	9.7	8.85	5.95	5.8	5.46	4.24	4.15	4.0
Velocity at Burnout (ft/sec)	3320	3290	3100	4050	3910	3760	4310	4200	4050
Burnout (g)	10.4	10.0	8.95	6.0	5.8	5.5	4.2	4.1	3.9
Traveled Distance at Burnout (statute miles)		3.15			7.5			12.0	

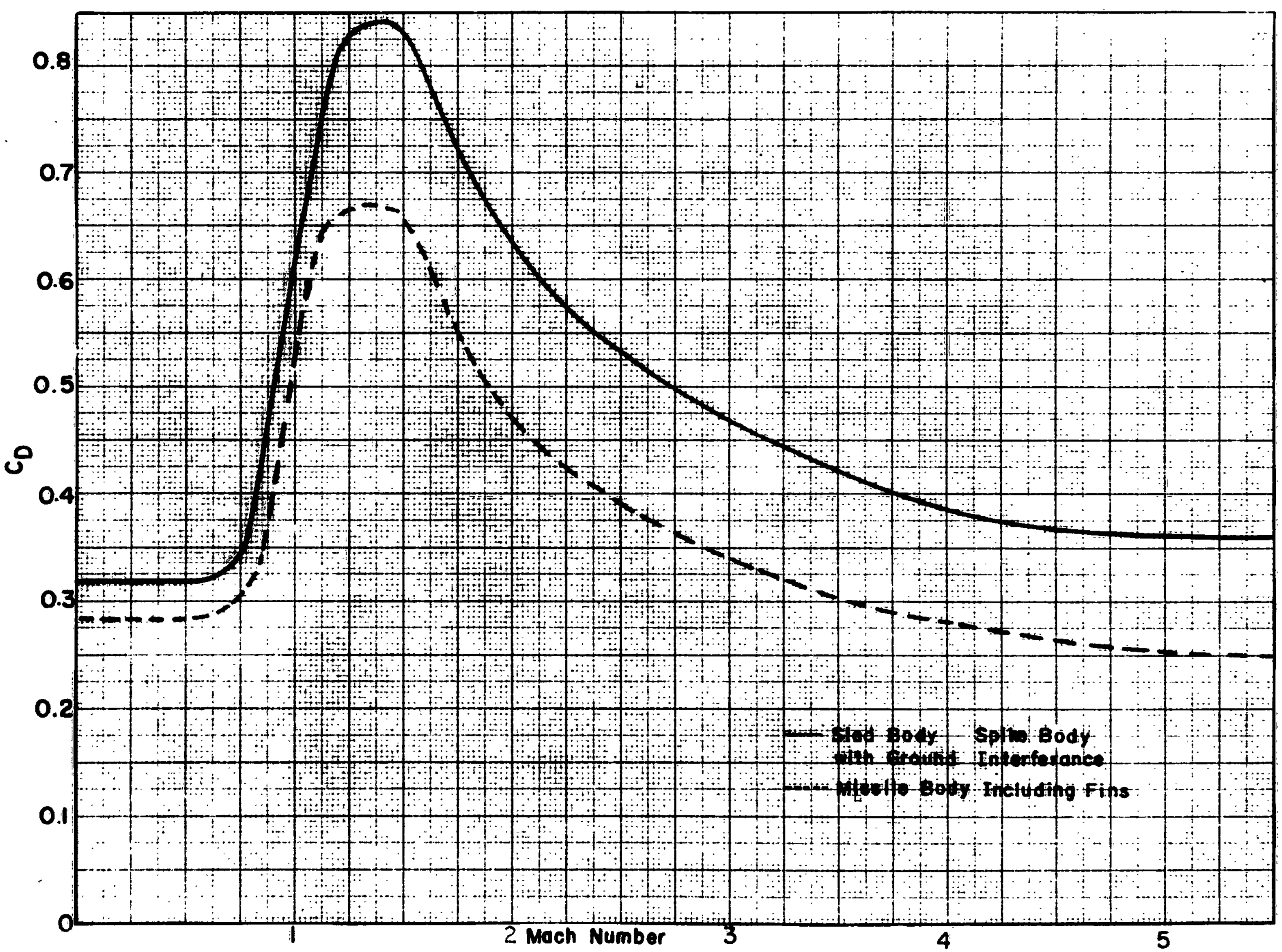

Figure I. Drag Coefficient Over Mach Number. Rocket Sled and Missile

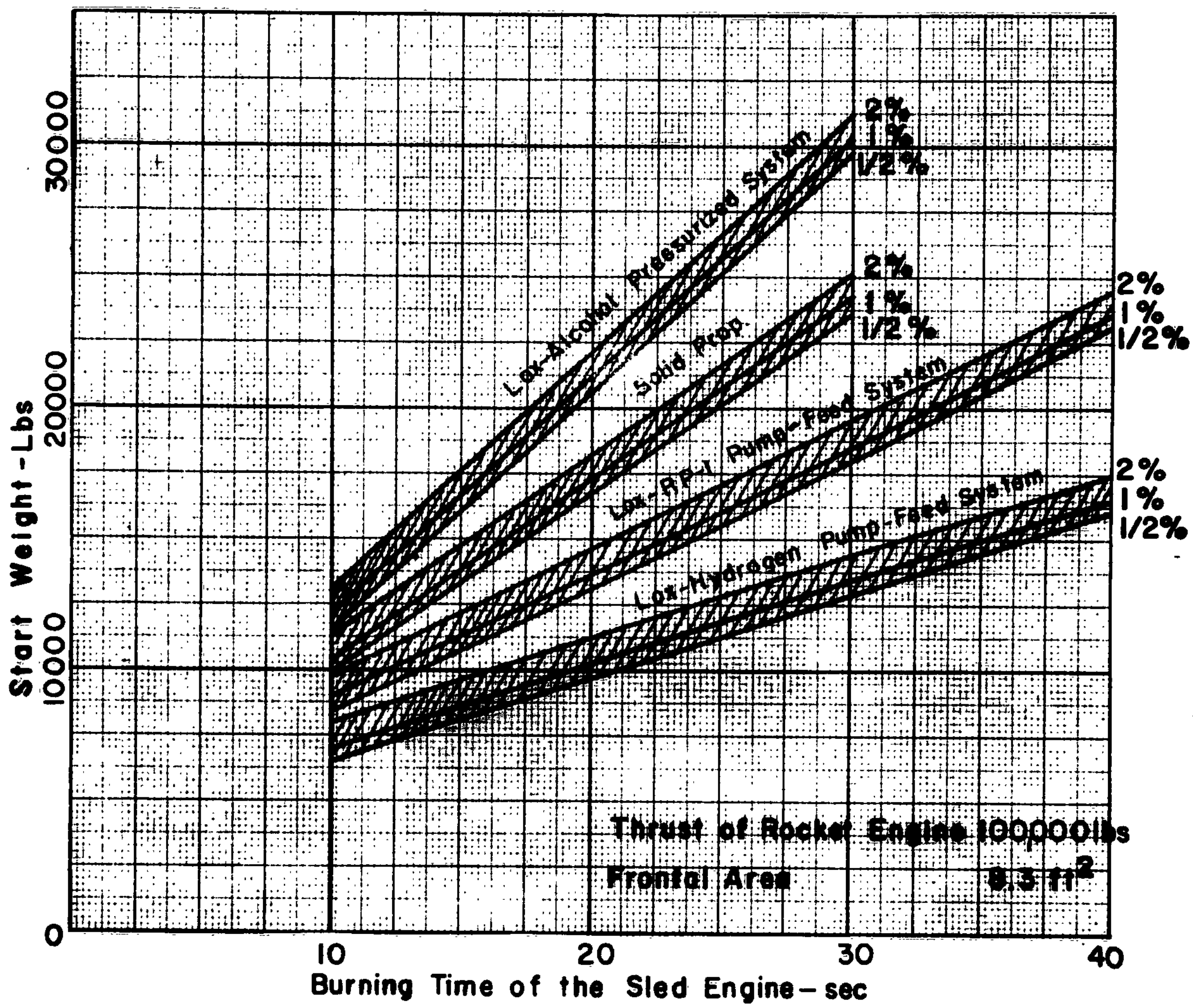

Figure 2. Start Weight Vs. Burning Time For Different Propellants and Payloads

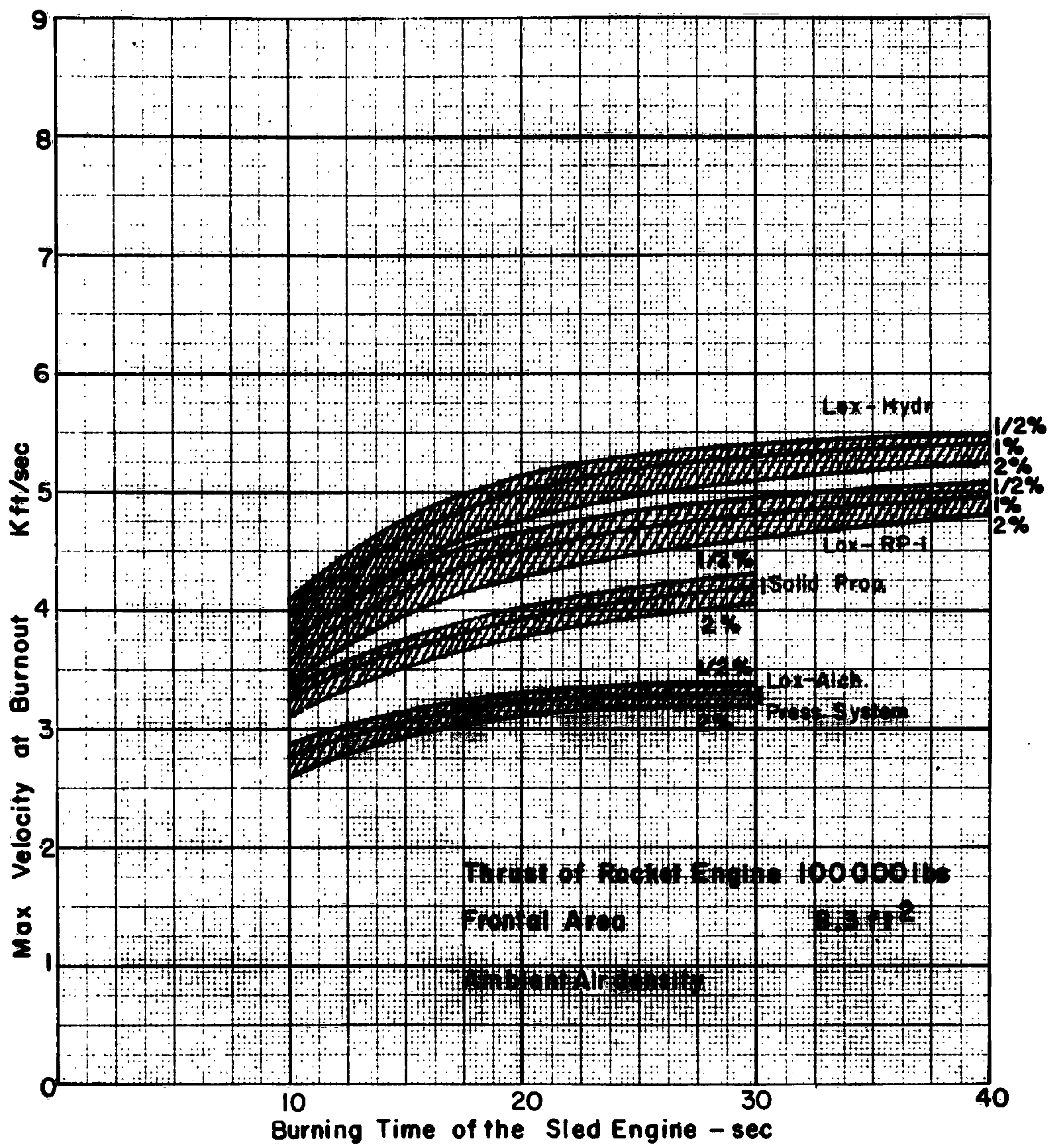

Figure 3. Maximum Velocity of Sled Vs. Burning Time for Different Propellants and Payloads

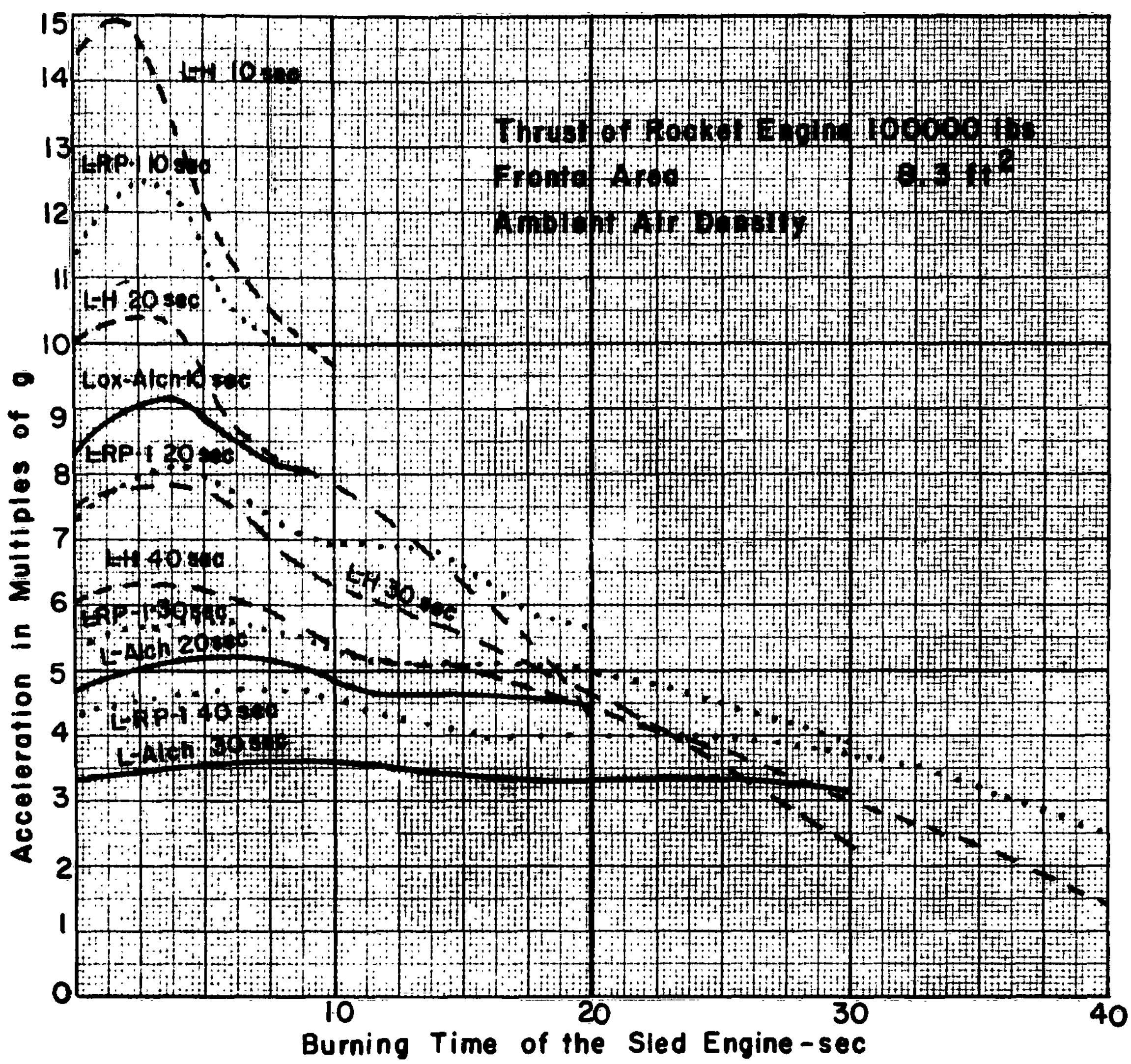

Figure 4. Acceleration Profiles Vs. Burning Time For Liquid Propelled Sleds With Different Specific Impulse and 1% Payload

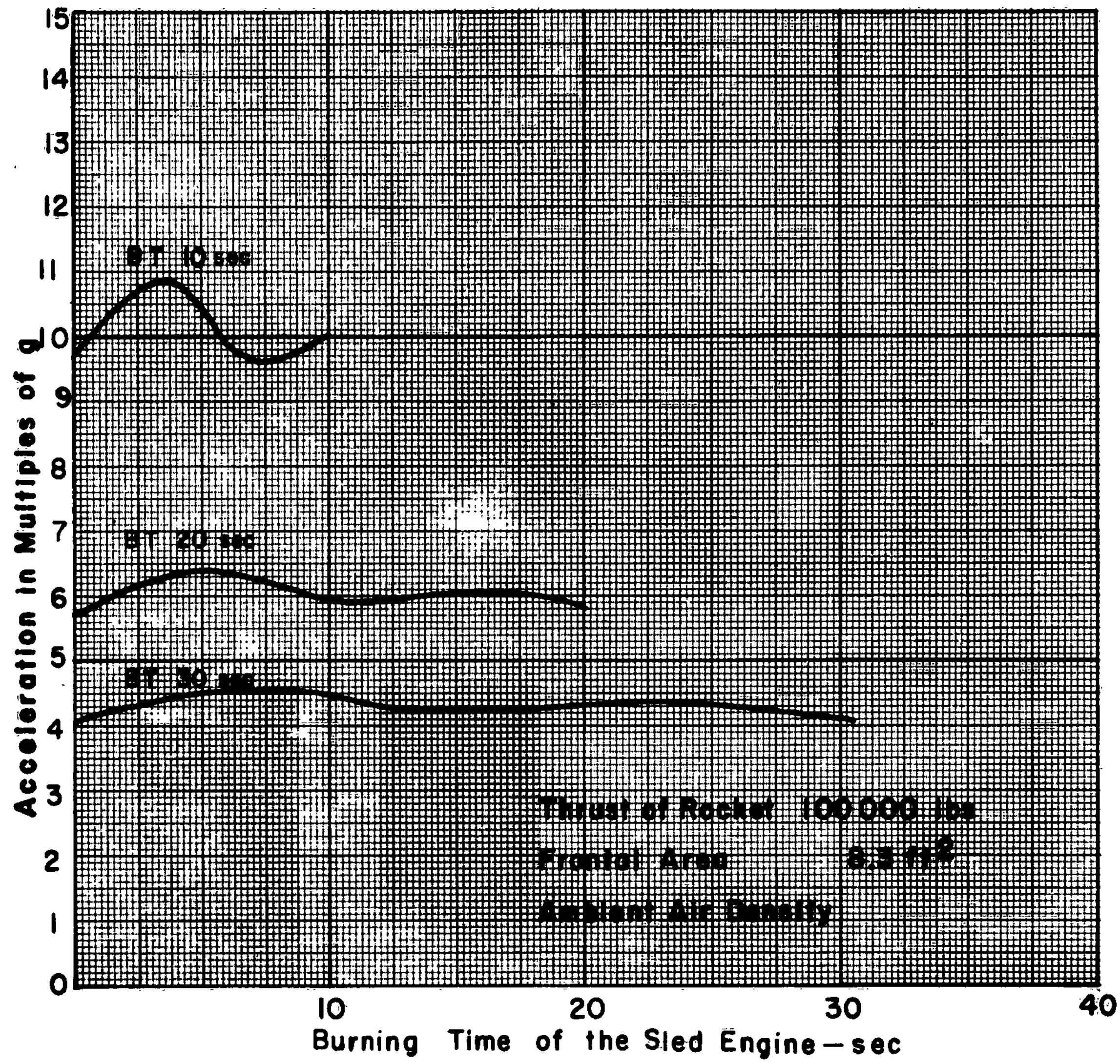

Figure 5. Acceleration Profiles Vs Burning Time For Solid Propelled Sleds and 1% Payload

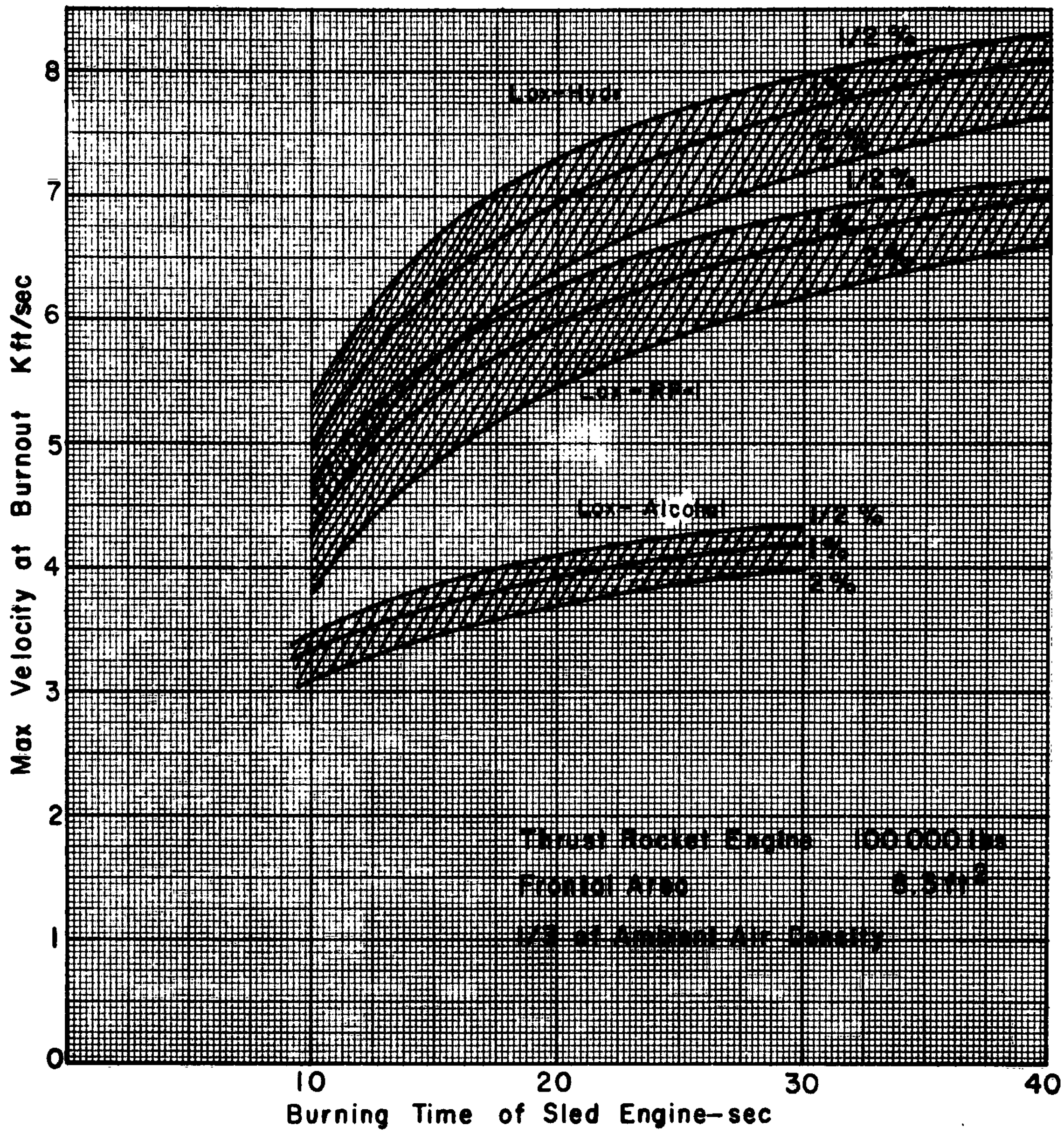

Figure 6. Maximun Velocity of Sleds Vs. Burning Time For Different Propellants and Payloads

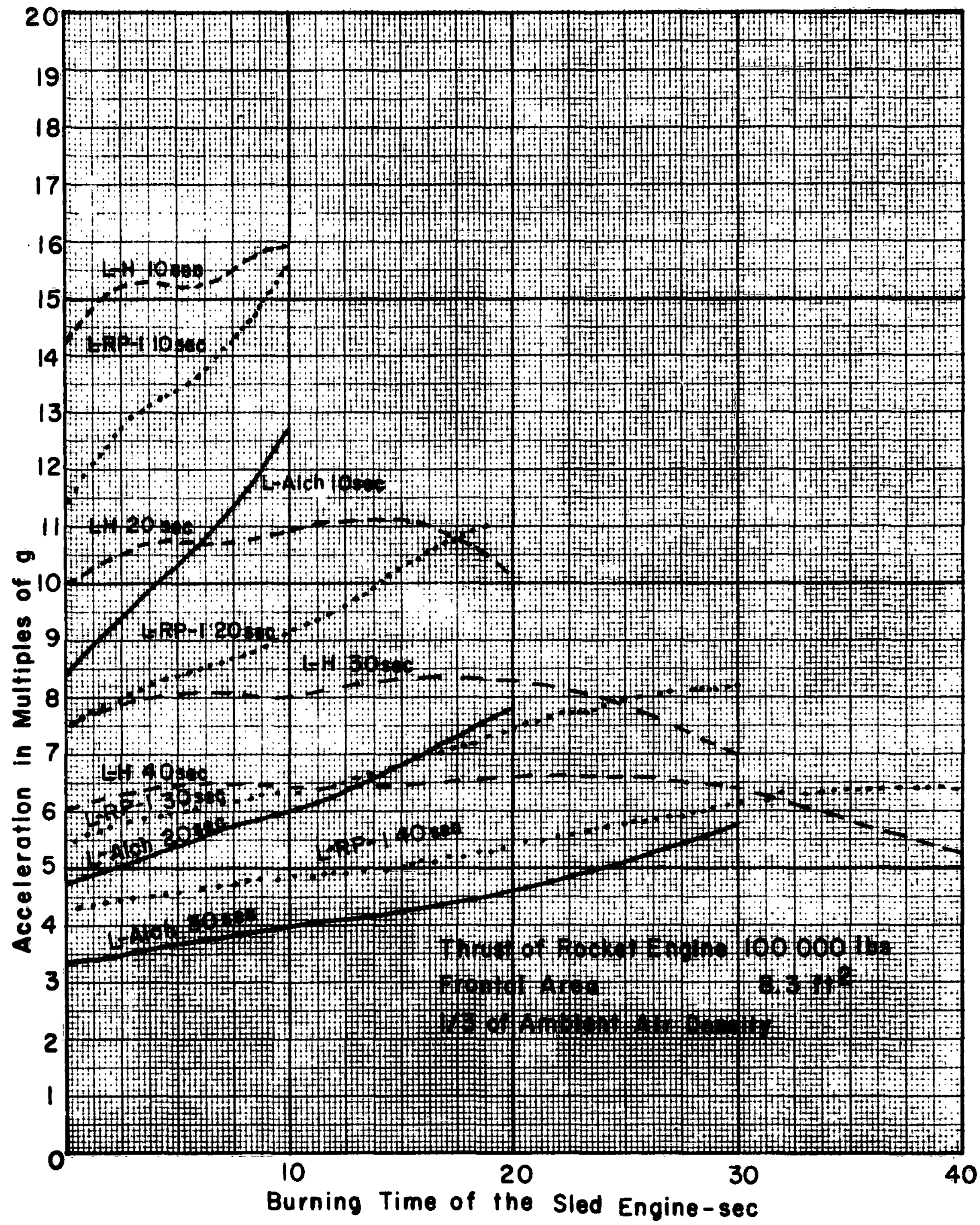

Figure 7. Acceleration Profiles Vs. Burning Time for Liquid Propelled Sleds With Different Specific Impulse and 1% Payload.

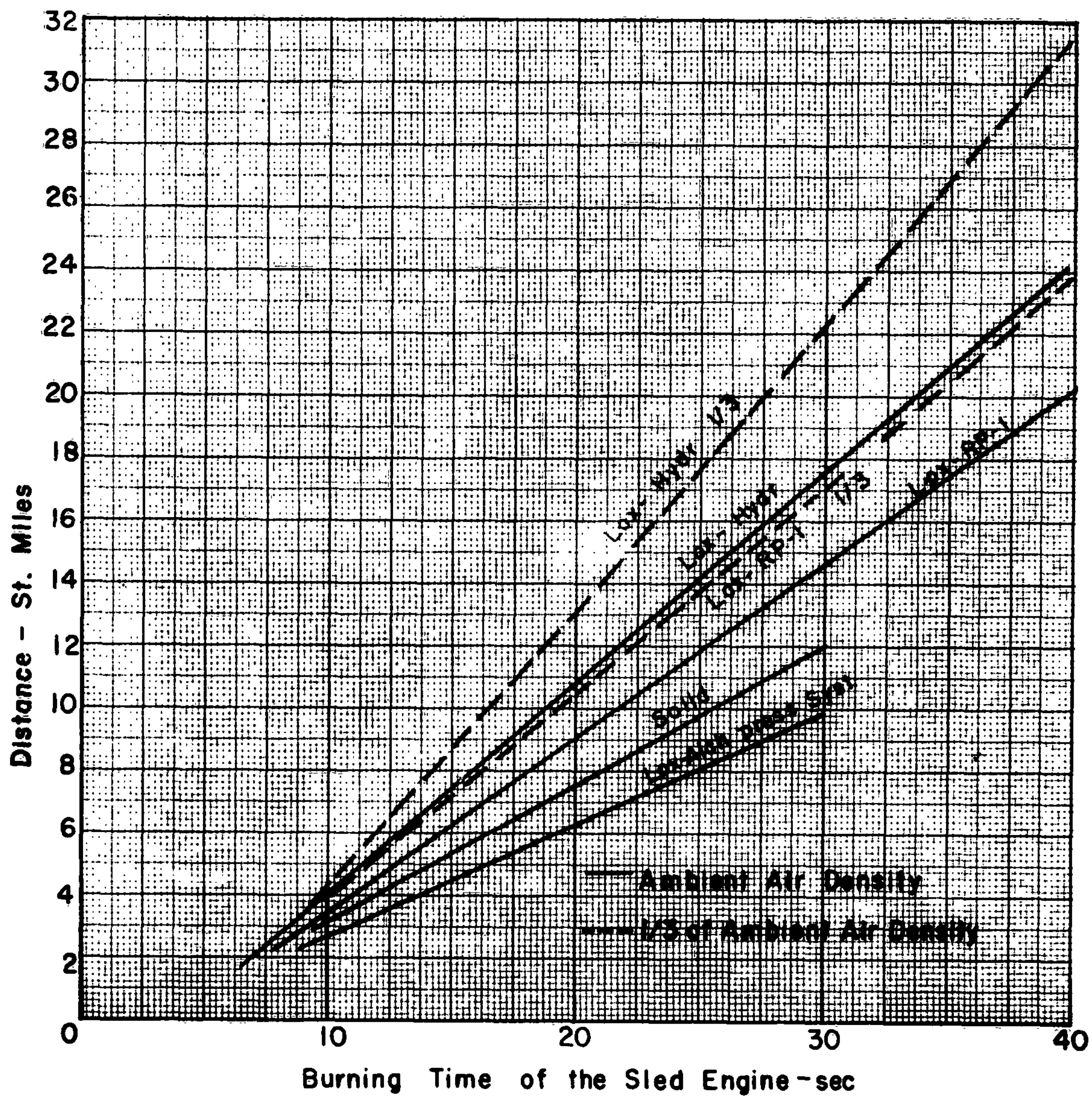

Figure 8. Distance Travelled at Burnout of Sleds With 100 000 Lbs Thrust and Different Specific Impulse and Burning Time in Normal and 1/3 Normal Density and 1% Payload

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